

EXHIBIT 3

Heavy-Duty Diesel Engines with Aftertreatment

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Abstract: Emission aftertreatment—diesel particulate filters and SCR catalysts—was widely introduced on heavy-duty diesel engines to meet US 2007 emission standards. However, there were differences in the technology paths—some manufacturers initially attempted to meet the 0.2 g/bhp-hr NO_x limit using high EGR rates, without NO_x aftertreatment. In medium-duty vehicles, there has been a trend to chassis certify complete Class 2b and Class 3 trucks. In Europe, Euro VI emission standards required the addition of particulate filters to Euro V engines with SCR technology.

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1. Introduction

Between 1994 and the end of 2006, emission standards for on-road heavy-duty diesel engines regulated by the US EPA focused on reducing NO_x emissions. During this period, NO_x emission requirements decreased from 5.0 to about 2.4 g/bhp-hr while PM emission limits remained static at 0.10 g/bhp-hr. Starting in 2007, emission limits for NO_x and PM dropped considerably. A new PM limit of 0.01 g/bhp-hr (0.013 g/kWh) required an order of magnitude reduction in PM emissions for 2007 MY engines while a NO_x limit of 0.2 g/bhp-hr (0.27 g/kWh) was phased-in between 2007 and 2010. For the period 2007-2009, 50% of a manufacturer's engines had to comply with the new NO_x limit of 0.2 g/bhp-hr while the remaining 50% of engines could continue to comply with the 2004 NO_x+HC limit of 2.5 g/bhp-hr. The averaging, banking and trading options in the regulation allowed manufacturers to produce engines with NO_x emissions between these two limits. As a result, most manufacturers designed almost all of their

2007-2009 engines to meet a NO_x family emissions limit of around 1.1-1.2 g/bhp-hr. Additional regulatory requirements for on-board diagnostics ([OBD](#)) also started to be phased-in starting in 2007.

To meet the 0.01 g/bhp-hr PM limit, all engine manufacturers adopted diesel particulate filters ([DPF](#)). To meet the interim NO_x requirements during the phase-in period most manufacturers chose to increase the levels of [EGR](#) from their 2004 engines to bring NO_x down to 1.1-1.2 g/bhp-hr. One manufacturer, Cummins, chose to implement [NO_x adsorber](#) catalysts in engines destined for Dodge Ram pick-up to meet an optional heavy-duty vehicle chassis certification limit that was legally equivalent to the 0.2 g/bhp-hr engine limit. For the full implementation of the 0.2 g/bhp-hr NO_x limit starting in 2010, most manufacturers opted for urea [SCR](#). The alternative to urea SCR, further increases in EGR was attempted by Navistar but ultimately proved to be unsuccessful.

In Europe, Euro V standards for heavy-duty diesel engines came into effect starting near the end of 2008 that reduced NO_x emissions to 2.0 g/kWh from the Euro IV level of 3.5 g/kWh. In 2013, Euro VI emission limits of 0.4 g/kWh NO_x and 0.01 g/kWh PM came into effect. Also, a PN limit of 8.0×10^{11} particle/kWh was introduced. OBD requirements were introduced at the Euro V level and increased in stringency for Euro VI. Off-cycle emission testing was introduced at the Euro VI level.

2. North American Engines

2.1 Manufacturers' Strategies

2.1.1 Summary

Table 1 summarizes both the interim 2007-2009 and final 2010 emission control strategies for most manufacturers of heavy-duty diesel engines for the US market. Applications range from pick-up trucks rated at 8500 lb GVW (Class 2b) up to Class 8 trucks.

Table 1

Emission control strategies for meeting US 2007 emission standards

Manufacturer	2007-2009		2010 and later		Comments
	Strategy	Emission Limits (NOx+HC/PM, g/bhp-hr)	Strategy	Emission Limits, NOx/PM	
Caterpillar	LP EGR + DPF	1.3/0.01	-	-	Active regeneration with burner
Cummins	HP EGR + DOC+DPF	1.1–2.5/0.01	HP EGR + DOC + DPF + SCR	0.2-0.5/0.01 g/bhp-hr	Several engine families had NOx FELs above 0.20 g/bhp-hr from 2010-2012. After 2013, most engines certified to 0.20 g/bhp-hr, a small number of families used FELs of 0.30-0.35 g/bhp-hr. Active regeneration with DOC
			HP EGR + DOC + DPF + NAC	0.2-0.4/0.02 g/mile	Dodge Ram pick-ups 2007-2012. Legally equivalent to 0.2 g/bhp-hr NOx.
			HP EGR + DOC + DPF + SCR	0.2-0.4/0.02 g/mile	Dodge Ram pick-ups 2013 and later. Legally equivalent to 0.2 g/bhp-hr NOx.
Daimler			HP EGR + DOC + DPF + SCR	0.2-0.4/0.02 g/mile	2010 and later 2500 and 3500 series Mercedes-Benz Sprinter, Freightliner and Dodge vans SCR: Fe zeolite
DDC	HP EGR + DOC+DPF	1.3/0.01	HP EGR + DOC + DPF + SCR	0.2/0.01 g/bhp-hr	
GM	HP EGR + DOC+DPF	1.3/0.01-0.02	HP EGR + DOC + DPF + SCR	0.46/0.01 g/bhp-hr	
				0.2-0.4/0.02 g/mile	SCR: Cu zeolite
Ford	-	-	HP EGR + DOC + DPF + SCR	0.2/0.01 g/bhp-hr	
			HP EGR + DOC + SCR +DPF	0.2-0.4/0.02 g/mile	SCR: Cu zeolite
Hino	HP EGR + DOC+DPF	1.2/0.01	HP EGR + DOC + DPF + SCR	0.2/0.01 g/bhp-hr	
Isuzu	HP EGR + DOC+DPF	1.2-1.4/0.01	HP EGR + DOC + DPF + SCR	0.2/0.01 g/bhp-hr	
			HP EGR + DOC + DPF + SCR	0.2-0.4/0.02 g/mile	SCR: Fe zeolite
Iveco			HP EGR + DOC + DPF + SCR	0.2/0.01 g/bhp-hr	
Mitsubishi	HP EGR + DOC+DPF	1.2/0.01			
Navistar	HP EGR + DOC+DPF	1.1-1.9/0.01	HP EGR + DOC + DPF	0.5/0.01 g/bhp-hr	Active regeneration with DOC
Paccar	-	-	HP EGR + DOC + DPF + SCR	0.2/0.01 g/bhp-hr	
Volvo/Mack	HP EGR + DPF	1.3/0.01	HP EGR + DOC + DPF + SCR	0.2/0.01 g/bhp-hr	“Passive” regeneration

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